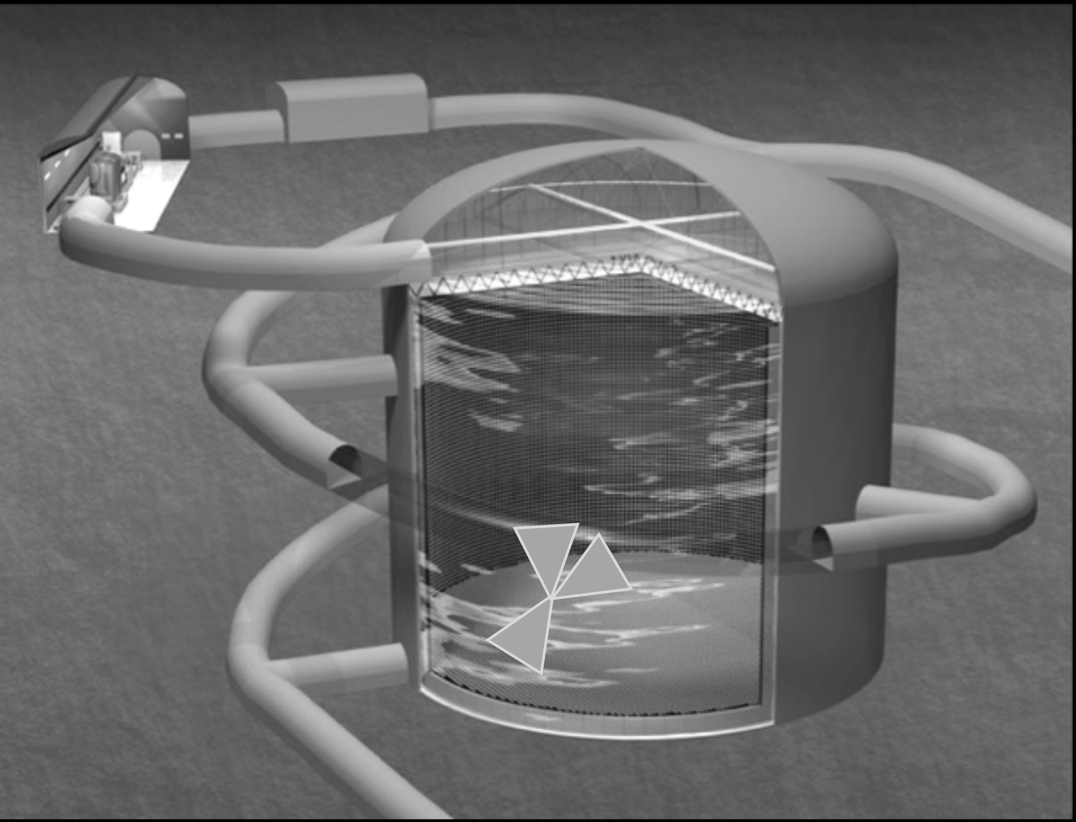
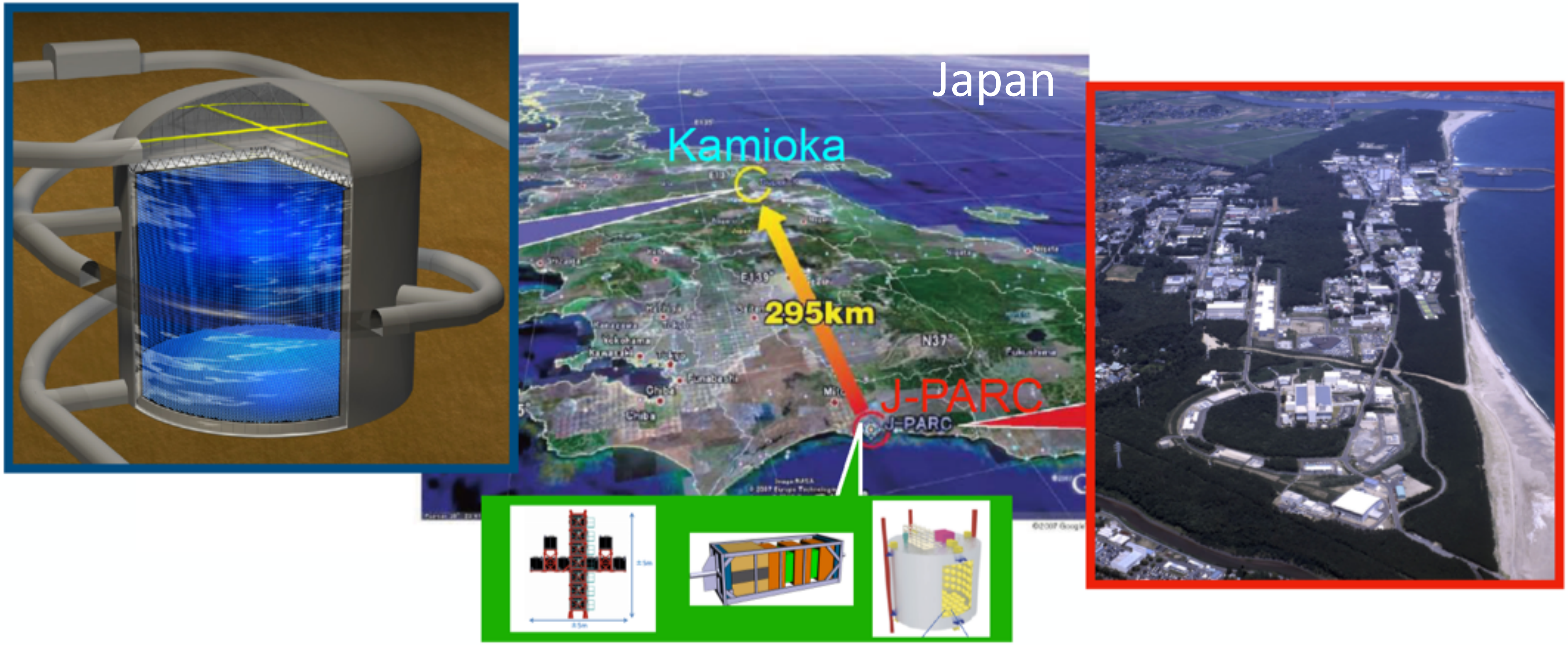
Hyper-Kamiokande:
Proton Decay and The Snowmass Process



Roger Wendell
Kyoto University
Snowmass
Rare Processes and Precision Frontier
Townhall Meeting
2020.10.02

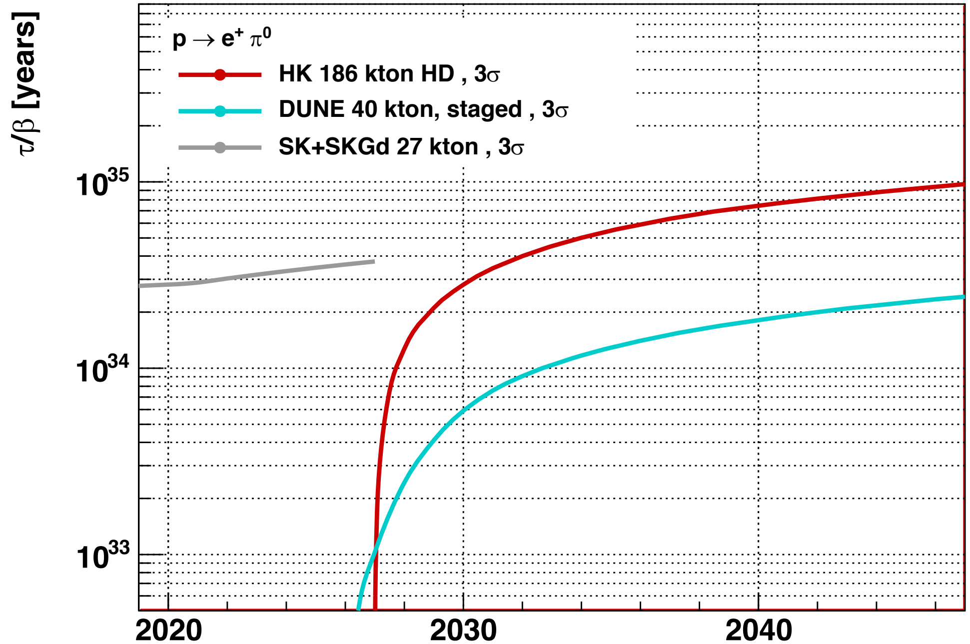
Hyper-Kamiokande (HK)

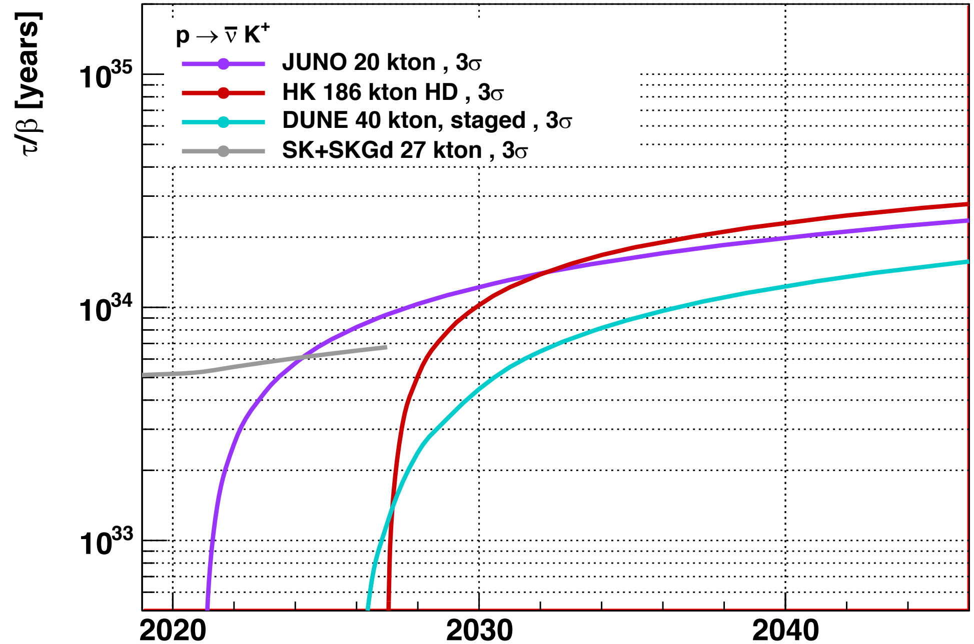


- Megaton-class water Cherenkov detector viewing natural neutrino sources and accelerator neutrinos from J-PARC
  - 260 kton volume (190 kton fiducial) well-suited for many nucleon decay searches
  - Successor to the Super-Kamiokande experiment with improved photosensors, calibration, etc.

- Japanese budget approved early in 2020
  - First formal collaboration meeting in September
  - Excavation of the Hyper-K cite and related civil construction is now underway
  - ~430 Collaborators from 19 countries

Nucleon Decay Discovery Potential at 3σ





$0 < p_{tot} < 100$ MeV/c		$100 < p_{tot} < 250$ MeV/c	
ϵ_{sig} [%]	Bkg [/Mton·yr]	ϵ_{sig} [%]	Bkg [/Mton·yr]
18.7 ± 1.2	0.06 ± 0.02	19.4 ± 2.9	0.62 ± 0.20

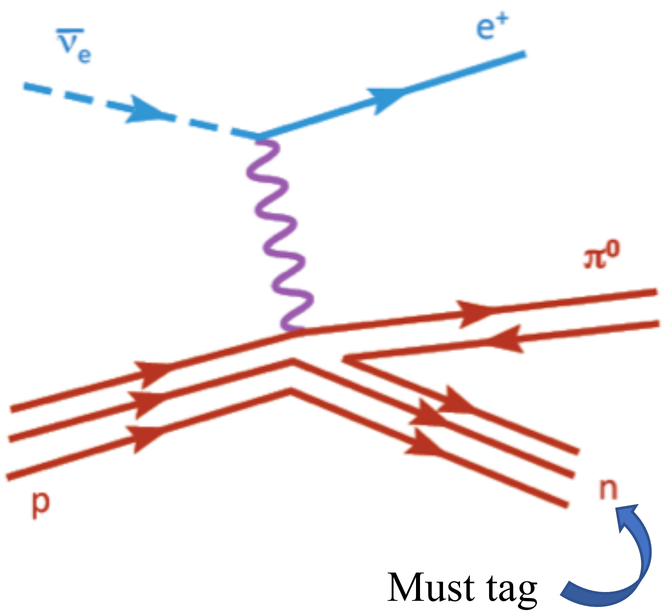
Prompt γ		$\pi^+\pi^0$	
ϵ_{sig} [%]	Bkg [/Mton·yr]	ϵ_{sig} [%]	Bkg [/Mton·yr]
12.7 ± 2.4	0.9 ± 0.2	10.8 ± 1.1	0.7 ± 0.2

- Excellent sensitivity to “flagship” decay modes and many other nucleon (dinucleon) decay modes
- Sensitivity projections are based on analyses at Super-Kamiokande, projected to Hyper-K exposures

- Physics Motivation for LOI
  - Emphasize need for improved experimental and theoretical studies of background processes
  - And for measurements of multiple modes (synergy: DUNE, JUNO, THEIA)

Reducing Backgrounds *and* Uncertainties for Discovery: $p \rightarrow l^+ M^0$

- Remaining backgrounds in Super-K analysis are atmospheric neutrinos
  - CCQE with π^0 from secondary hadronic interactions, CC $\nu_{\mu,e}\,\pi^0$, and CC $\nu_{\mu,e}\,\pi^{+/-}$, all with no tagged neutron in the final state



Uncertainty [%]		$p \rightarrow e^+\pi^0$ low P_{tot}	high P_{tot}
Efficiency			
	π-FSI	2.8	10.6
	Correlated decay	1.9	9.1
	Fermi momentum	8.5	9.3
	Reconstruction	4.6	5.6
	Total	10.2	17.7
Background			
	Flux	7.0	6.9
	Cross section	14.5	10.4
	π-FSI	15.4	15.4
	Reconstruction	21.7	21.7
	(neutron tag)	10	10
	Total (I/II/III)	31.2	29.4
	(IV)	32.7	31.1
Exposure		1.0	1.0

PRD 95, 012004 (2017)

- <u>What Common or Joint Efforts are needed?</u>
- Hyper-K and the PDK community in general will benefit from better experimental and theoretical understanding of
  - Neutrino interactions in the ~1-4 GeV range
  - Final state and secondary interactions of π, protons, neutrons (and accompanying n production)
  - Neutron multiplicity in neutrino interactions

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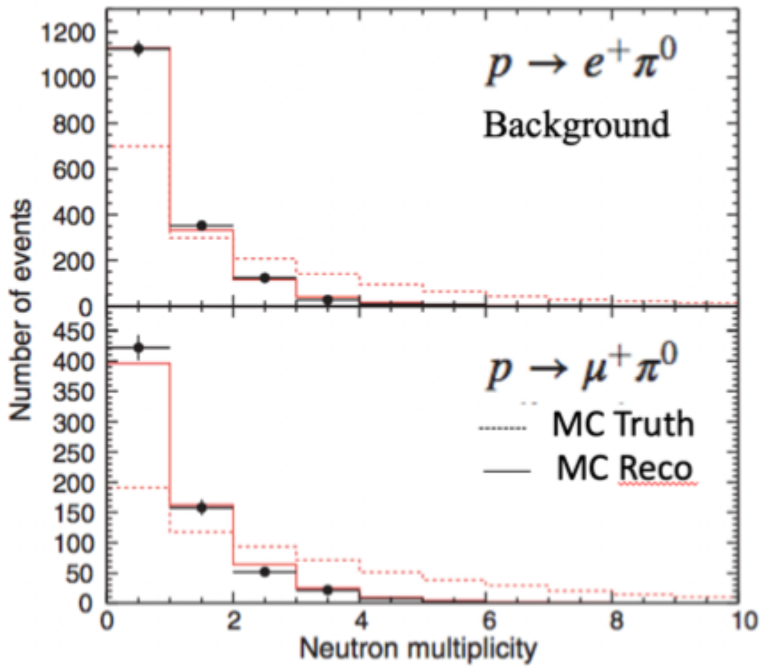

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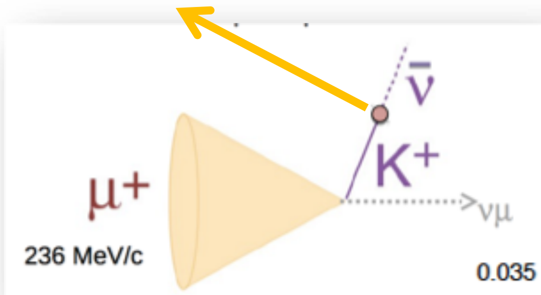
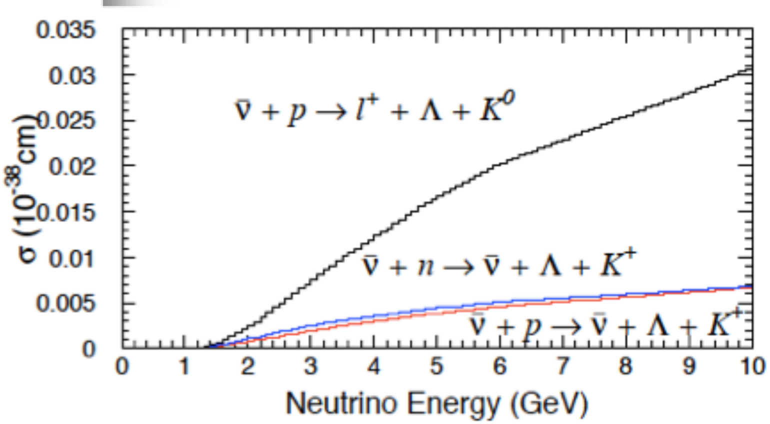
Reducing Backgrounds *and* Uncertainties for Discovery: $p \rightarrow \nu K^+$

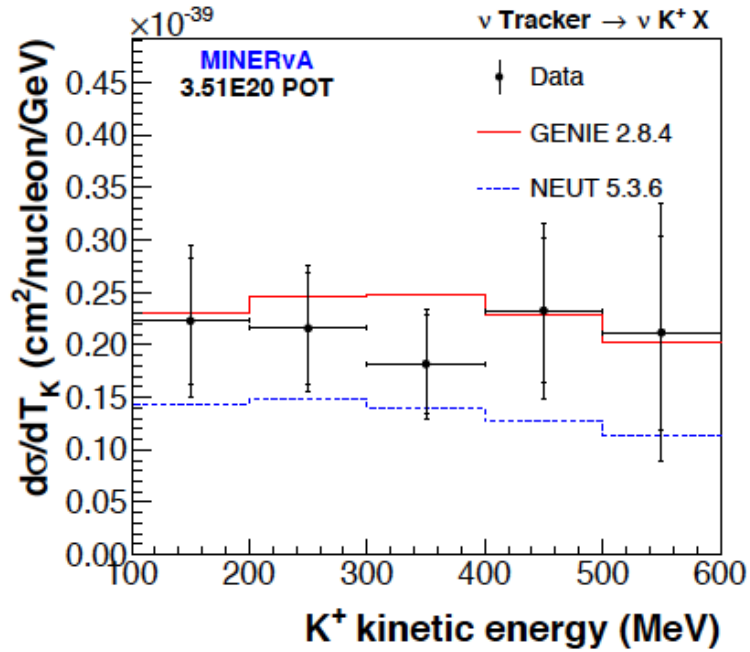
- Since the K^+ from PDK is unseen in water the initial state cannot be reconstructed and hence dominant background is anything that produces a kaon

Prompt γ from recoiling nucleus (Δt ~ 12 ns)

arXiv:1611.02224v2







- <u>What Common or Joint Efforts are needed?</u>
- Hyper-K and the PDK community in general will benefit from better experimental and theoretical understanding of
  - Associated kaon production via neutrino and cosmogenic production
  - Nuclear de-excitation spectrum of ^{16}O following nucleon knock out, nuclear modeling

- <u>Work between now and Snowmass?</u>
- Finalizing Hyper-K simulated sensitivities, with focus on backgrounds and projected uncertainties
    - Reconstruction improvements will strengthen need for similar improvements in other systematics

- <u>Schedule for a contributed paper?</u>
  - Hyper-K contributed paper is being developed across subgroups of the experiment, including those focused on non-PDK physics, expect submission close to the July 31st deadline.

- <u>What would Hyper-K like to come out of the Snowmass process? Hope for:</u>
  - Continued support of general neutrino and nucleon decay programs, emphasis on synergy and complementarity of current (Super-K) and future programs (DUNE, HK)
  - Support of measurements that underlie the discoveries sought in those programs, such as neutrino interactions, meson interaction in media, nuclear modeling, etc.
  - Increased participation in Hyper-K from U.S. institutions. Historically the U.S. has played strong roles in predecessor experiments in Japan

Thank You